GENERAL
ENGINEERING
LABORATORY

OTS PRICE

XEROX $ _1.00_

MICROFILM $ _0.50_

DEVELOPMENT OF LOW TEMPERATURE

DIELECTRIC COATINGS

FOR ELECTRICAL CONDUCTORS

BY

K.N. MATHES

JANUARY 15, 1963

GENERAL (( )) ELECTRIC

Sixth Quarterly Report
January 15, 1963

Development of Low Temperature Dielectric Coatings
for Electrical Conductors

Contract No. NAS8-2442
Control Number: TP85-498(CPB-02-1096-61)
(W/O #8500-0-0224-000-8500-11-431)

General Electric Company
Missile and Space Vehicle Department
Philadelphia, Pa.

Report Prepared by:

K. N. Mathes
Advanced Technology Laboratories
General Electric Company
Schenectady 5, N.Y.

Report Prepared for:

George C. Marshall Space Flight Center
Huntsville, Alabama

Sixth-Quarterly Report
January 15, 1963

DEVELOPMENT OF LOW TEMPERATURE DIELECTRIC COATINGS
FOR
ELECTRICAL CONDUCTORS

INTRODUCTION

The evaluation of the effect of thermal aging on the performance of wire insulation at cryogenic temperatures constitutes the major effort of the present work. The procedures and test facilities were described in the fifth quarterly report dated October 15, 1961. This sixth report summarizes flexibility and dielectric measurements obtained to date on wires aged in air at 120 C and 250 C and in a vacuum of between 10^{-5} and 10^{-6} Torr at 120 C. Breakdown measurements are in progress and will be reported in the seventh quarterly report. The thermal aging program continues.

Preliminary tests in the study of the crushing of wire insulation at cryogenic temperatures are described in this report.

The program includes also the development and evaluation of flat ribbon cable for cryogenic applications. Test results for several types are reported.

The dielectric evaluation of cryogenic liquids has been delayed by the pressure of other work. However, ideas for simplified approaches have been developed and will be tried in the coming quarter.

SUMMARY AND CONCLUSIONS

As a general observation it is interesting to note that at the start of the subject program relatively little information existed on the properties of non-metallic materials at cryogenic temperatures. Catalized at least in good part by this program, a number of other investigations on several types of non-metallic materials at cryogenic temperatures are now underway.

Wire Evaluation

The remarkable properties of ML insulation at cryogenic temperatures continue to be born out as evaluation continues. The intrinsic liability of possible poor continuity in a solution coated wire appears to be the only limitations. Such a limitation will be of functional importance only if discontinuities by chance register in the bundled construction. For cryogenic applications it seems feasible to dielectricly test lengths of such bundled conductors so as to eliminate any with discontinuities in contact.

To the superior mechanical flexibility of ML at 4.2 K can now be added the amazingly good performance under crushing stress as well. The proposed study of crushing resistance in which shear is combined with compression seems important since such conditions may exist in practical situations.

If a positive spacer is needed of greater thickness than is feasible with film coating (triple ML is available), the aluminum phosphate inorganic bonded and the ML coated felted asbestos insulations can be used, which also possess superior electrical and mechanical properties at cryogenic temperatures. Such asbestos insulation is limited by poor electrical properties and moisture resistance at more normal temperatures. Such problems can be alleviated by using the asbestos insulation over an ML coating with possible advantage in some applications.

Inorganic aluminum-phosphate bonded asbestos has obvious advantages for applications involving atomic radiation. However, information from other sources continues to show relatively good performance of ML and H film under radiation also.

Thermal and Vacuum Aging

Perhaps the most important conclusion to be drawn from the quarter's work concerns the absence of adverse affects due to vacuum in thermal aging. In fact, quite the reverse is true since the absence of oxygen prolongs the high temperature life of many organic insulating materials as illustrated in this case by Formex. The improvement in thermal aging to be had be eliminating oxygen has been known for many years. In contrast, the dire prophesies of the prophets of doom concerning the adverse effects of space environment on the performance of insulating materials do not stand up in the light of experimental fact. Based upon the physics of partial pressure, it seems exceedingly unlikely that reducing pressure beyond that used in this program will produce unexpected adverse effects.* In fact, pressures of the order of a few mm. of Hg may be more important because of the presence of oxygen and the possibility of glow discharge at relatively low voltages.

The excellent thermal capability of ML insulation has been recognized based on other work but it is useful to record that this superiority persists when measurements on thermally aged wires are made at liquid helium temperatures. However, it is also apparent that changes in ML produced by thermal aging may be detected with flexibility measurements at cryogenic temperature before they can be detected at room or elevated temperatures.

As expected on the basis of other work the cryogenic performance of ML and the asbestos insulated wires is essentially unaffected by 60 days exposure at 250 C except for slight effects apparently introduced by development of copper oxide at the interface between

* This conclusion does not hold necessarily of course for other areas beyong the scope of this work such as lubrication, contact sticking, etc. on which the author is unqualified to comment.

the conductor and the insulation. If such oxidation is expected
in service, aluminum or nickel coated copper should probably be
used if loss of insulation adhesion will be functionally important.
The oxidation does not appear to affect the performance of extruded
Teflon coatings which is somewhat inferior to ML and asbestos in
flexibility at cryogenic temperatures.

Obviously neither PVC nor Formex can be expected to perform
adequately at 250 C. The initial poor flexibility of PVC also rules
it out if such conditions must be met in cryogenic applications.
The very poor flexibility of Formex in liquid helium after aging in
air for 60 days at 120 C came somewhat as a surprise to the author
(evaluation at room temperature does of course show some but not
serious degradation). The lack of apparent degradation of the PVC
as measured at room temperature after aging 60 days at 120 C in
both air and vacuum is interesting and the results after 120 days
will be in consequence of great importance.

Flat Ribbon Cable

The superior performance of H film in ribbon cable supports
the attempts to obtain additional constructions utilizing this
material. It is suggested also that H film may be very useful in the
outer insulation layer over bundled conductors (outside the scope
of the subject work).

The geometry of the ribbon cable, as expected, is important
in determining the flexibility at cryogenic temperatures. It is
recommended that minimum thickness of both conductor and insulating
film be used in the construction of ribbon cable for cryogenic
applications.

OBSERVATIONS AND SUMMARY OF TEST RESULTS

Wire Evaluation

Flexibility

The effect of thermal aging on the flexibility of wire insulation
measured after immersion in liquid helium (4.2 K) is summarized in
Table I and given in detail in Table II. After 60 days in air at
250 C the copper is oxidized under the insulation in every case.
The black oxide generally loses adhesion for the underlying copper
(which may have an adherent layer of red oxide) and may adhere in-
stead to the insulation so that flexibility may be impaired. Such
effects are noticed when both the ML and the asbestos coatings are
bent about small mandrels. The ML insulation develops radial cracks
but does not spall off the wire. It may tend to tube a little. The
asbestos felting on the 1/8" or 1/4" mandrel may open up more than
it does before thermal aging. In other respects Teflon, ML and the
asbestos coatings possess remarkable resistance to thermal aging at
250 C. As expected neither PVC (plasticized polyvinyl chloride)
nor Formex (polyvinylformal) can withstand 60 days at 250 C without
serious degradation.

Table I

Effect of Thermal Aging
on
Repeated Mandrel Flexibility in Liquid Helium

Wire	In Air at 250 C 60 days	In Air at 120 C 60 days	In Vacuum at 120 C 20 days	60 days
Teflon (Extruded)	No significant change. Fails on 1" mandrel	No significant change. Fails on 1" mandrel	No significant change.	No significant change Fails on 1" mandrel
PVC	Failed initially on 1 3/4" (largest) mandrel so aging, if any, cannot be evaluated.		changes due to	
Heavy Formex	Charred	Failed completely on 1 3/4" mandrel (3/4" mandrel before aging)	No significant change	Radial cracks on 1½" mandrel (1" before aging).
HML	Radial cracks on ½" mandrel - (OK on 1/8" mandrel before aging)	No significant change.	No significant change.	
Aluminum-Phosphate felted asbestos	Opens up on ¼" mandrel (No opening on 1/8" mandrel before aging	No significant change	No significant change	
ML Coasted Felted asbestos	Opens up on 1/8" mandrel (No opening on 1/8" mandrel before aging	No significant change	No significant change	

TABLE II

REPEATED MANDREL FLEXIBILITY IN LIQUID HYDROGEN

Test Conditions: Reverse Bend - 10 Times or Less as Indicated ( )

Insulated Wire	Mandrel Dia.	As Manufactured	Aged at 120 C, Air for 60 Days	Aged at 120 C Under Vacuum for 20 Days	Aged at 120 C, Vacuum for 60 Days	Aged at 250 C in Air for 60 Days	Mandrel Dia.-Ins.
Teflon (extruded) Color - White	1/4"	9/20 Failed on (1)	No Test	No Test	No Test	No Test	1/4
	1/2"	10/12 " on (1)	Failed	Failed	Failed	Failed - Split & Stripped Off	1/2
	1"	"	"	"	"	No damage	1
	1 1/4"	No damage	No damage	No damage	"	"	1 1/4
	1 1/2"	"	"	"	"	"	1 1/2
	1 3/4"	"	"	"	"	"	1 3/4
Surprenant RC22U Single PVC - No Overcoating	1/8"	4/26 Failed on 1 Forward	No test	No test	No test	No test	1/8
	1/4"	" "	"	"	"	"	1/4
	1/2"	5/4 "	Failed	Failed	Failed	"	1/2
	1 1/4"	"	"	"	"	"	1 1/4
	1 1/2"	"	"	"	"	"	1 1/2
	1 3/4"	"	"	"	"	"	1 3/4
Heavy Formex	1/8"	8/22 Failed	Failed	No test	Failed	No test - Insulation charred and damaged at temp. of 250 C	1/8
	1/4"	"	"	"	"	"	
	1/2"	"	"	"	Radial cracks No breaks	"	1/2
	1"	11/12 Radial Cracks - Spaced Groups	Radial Cracks - Single, Spaced	"	"	"	
	1 1/4"	"	No damage	"	"	"	1 1/4
	1 1/2"	" - Few Groups	"	"	"	"	1 1/2
	1 3/4"	"	"	No damage	No damage	"	1 3/4
G-E EML	1/8"	8/22 No damage	No damage	No damage	No damage	Failed - Radial welts on inside result in radial breaks and tubulation	1/8
	1/4"	"	"	"	"		1/4
	1/2"	"	"	"	"		1/2
	3/4"	No test	"	"	"	No damage - Inside welts faintly visible	3/4
	1"	"	"	"	No damage	No damage	1
Phelps Dodge EML	1/8"	9/20 No damage	No damage	No damage	No damage	Failed - Radial welts on inside with sections of ML curling off	1/8
	1/4"	"	"	"	"	Failed - Radial welts on inside	1/4
	1/2"	"	"	"	"	Failed - Resulting in radial breaks in ML at intervals along wire	1/2
	3/4"	No test	"	"	"	No damage - Inside welts faintly visible	3/4
	1"	"	"	"	"	No damage	1
Aluminum Phosphate - Asbestos	1/8"	Radial cracks	Radial cracks & loosening " No copper showing "	Asb. roughed up in spots	Failed	Radial cracks at intervals on outside - lifted in some cases	1/8
	1/4"	"	"	Radial cracks	Radial cracks	Asbestos cracked apart in spots and opened up	1/4
	1/2"	Good condition	Good condition	Radial cracks, lifting	Radial cracks but no copper showing	Radial cracks at various points asbestos starting to break - No copper visible	1/2
	3/4"	No damage	No damage	Asb. pulled up in some areas No copper visible	Good condition	No apparent damage	3/4
	1"	"	"	No damage	No damage	No damage	1
ML coated Asbestos	1/8"	Radial cracks in ML	Radial cracks, pulling & lifting?	Radial cracks in ML	Some cracking and pulling of ML - but not serious	Radial cracks - Some lifting & pulling of asbestos	1/8
	1/4"	" "	Radial cracks - Not serious	Radial cracks in ML	Radial cracks in ML	"	1/4
	1/2"	No damage	- Not serious	Few radial cracks in ML	Few radial cracks in ML	No apparent damage - no bad damage	1/2
	3/4"	No test	No damage	No damage	No damage	No damage	3/4
	1"		"		No damage	No damage	1

Additional Wires

Insulated Wire	Mandrel Dia.	As Manufactured
Phelps Dodge, Triple ML	1/8"	No damage
	1/4"	"
	1/2"	"
	3/4"	"
	1"	"
Ceramic - Exe	1/8"	Failed - Insulation curled off - Leaving a greenish granular appearance beneath
	1/4"	" - Radial cracks on inside and crystalizing appearance with some areas about to scale off
	1/2"	"
	3/4"	" - Radial welts on inside - light blotchy color green due to bending
	1"	" - Radial marks on inside No damage

Jan. 15, 1963

After 60 days at 120 C no significant change in the flexibility at cryogenic temperatures occurs for ML, Teflon or the asbestos coatings as would be expected from their recognized thermal capability and excellent performance at 250 C. Since PVC is so brittle anyway at 4.2 K, changes after aging at 120 C, if they occur, cannot be evaluated. However, it should be noted from the results in Table III, that the room temperature flexibility of PVC is not adversely affected after aging 60 days at 120 C. The aging of PVC in other studies has been found to relate to plasticizer characteristics and to the effectiveness of the inhibitor against formation of HCl. Decreased flexibility does not seem generally to develop gradually during the thermal aging of PVC but rather a "threshold" occurs at which brittleness develops suddenly. It will be interesting to see if this threshold is reached in 120 days at 120 C (the next aging period). It is noteworthy that the hard vacuum did not cause a sufficient loss of plasticizer at 120 C to produce enbrittlement. It is probable that not much outgassing occurred after the first several days at 120 C. For the first few days a vacuum of about 10^{-4} was held which improved rapidly to better than 10^{-5} and then improved more slowly to about 2×10^{-6} Torr.

In contrast the difference in the aging of Formex in air and vacuum at 120 C is marked. As has been observed before, particularly with tests in nitrogen, oxygen (in air) has a deleterious effect. Certainly any possible effect that vacuum may have in removing volatile components is more than overbalanced by the absence of degradation from oxidation. The relatively greater degradation of Formex in air as compared to vacuum is demonstrated both at cryogenic temperature (Tables I and II) and at room temperature (Table III). There is no evidence of the presence of appreciable black copper oxide on the wires aged in air at 120 C. Other work indicates that such oxide does not form at temperatures much below 175 C.

Dielectric Properties

Capacitance and dissipation factor measurements have been made on the cabled test specimen described in the fourth quarterly and final report dated July 16, 1962 and shown as Fig. 1 and Photo. 1 of that report. The samples were made before aging and a shrinkable Teflon rather than PVC tubing (Thermofit) was used in the assembly. The samples were handled as carefully as possible since it is recognized that mechanical disturbance would affect the measured values.

In this series, the measurements at 1 Kc have been made with a new General Radio transformer ratio arm bridge which permits three terminal measurement of much lower values of dissipation factor than the previously used Wayne Kerr bridge particularly with small values of capacitance. As noted in the footnote of Table IV, the bridge sensitivity for dissipation factor at 1 Kc is at least .00005. It is amazing that nearly every value measured on the thermally aged wire samples is below even this tremendous sensitivity. A number of cross-checks have been made with the Wayne Kerr bridge. Very close agreement in capacitance is obtained and in dissipation factor

Table III

Repeated Mandrel Flexibility Tests in Air at Room Temperature
after
Thermal Aging

	Aged 60 days, 120 C In Air	Aged 60 days, 120 C In Vacuum
Heavy Formex	1/8" Failed - Splits & peels off 1/4" " " " " 1/2" No damage* 3/4" " " * 1" " " *	No damage - Formex looks tight at cut ends " " " " ". " " " " " " " " " "

* Although no damage is shown
in the flexed area the cut ends
of the wire look as though the
Formex is loose and might split
easily as it did on the 1/8" &
1/4" mandrels.

PVC	1/8" No damage 1/4" No test 1/2" No test 3/4" No Test 1" No damage	No damage " " " "

Note: No effect of thermal aging on room temperature flexibility
was expected or noted for Teflon, HML or the asbestos insulated
wires.

Table IV

Effect of Thermal Aging on Dissipation Factor (tan δ) – 1 Kc

Wire	at 23 C Before Aging	at 23 C After 60 das. 120 C in air	at 4.2 K After 60 das. 120 C in air	at 23 C After 60 das. 120 C in Vac	at 4.2 K After 60 das. 120 C in vac.	at 23 C After 60 das. 250 C in air	at 4.2 K After 60 das. 250 C in air
Teflon	.00035 .00057 .00087 .00107	.00024 .00034	.00000* .00000	.0006 .0008	.00007 .00015		
PVC	.062 .100 .060 .059		.00000 .00000	.0702 .0678	.00000 .00000		
Heavy Formex	.0064 .0058 .0057 .0058	.00974 .00877	.00000 .00002	.00539 .00606	.00012 .00000		
HML (GE)	.00097 .00096 .00088 .00115 .00092 .00083	.00087 .00089	.00000 .00000	.00076 .00097	.00000 .00000	.00165 .00117	.00000 .00000
HML (PD)	.0013 .0016 .0021 .0018	.00096 .0011	.00000 .00000	.00134 .0012	.00000 .00000		
Aluminum phosphate Felted Asbestos	0.377 0.322 0.372 0.323 0.452 0.486	0.2055 0.1835	.00000 .00000	0.169 0.156	.00000 .00000	0.219 0.250	.0000 .00000
ML Coated Felted Asbestos	0.26 0.22 0.26 0.20	0.243 0.211	.00000 .00000	0.275 0.218	.00000 .00000		

* The actual reading is reported. The precision of the bridge is limited by the accuracy of the ... is known to be better than .000005.

at values within the range of the Wayne Kerr bridge. It is recognized now that some of the very low values of dissipation factor obtained earlier in the program with the Wayne Kerr bridge have been more or less in error. Such very small errors have little or no significant meaning in terms of the conclusions to be drawn.

Dissipation factor measurements at 23 C and 4.2 K before and after aging are reported in Table IV. It must be remembered that for the cabled sample the dissipation factor is related to the sample configuration and is not the value for the material itself. (though close to it). The value is useful for comparison and it also indicative of the practical situation in which wire samples are cabled together. However, the changes indicated in Table IV may have relatively little functional significance but are more meaningful in terms of understanding the effect of thermal aging and measurement temperature. All of the samples were allowed to reach moisture equilibrium at 50% RH and 23 C.

Table IV is useful in showing the effect of thermal aging on the dissipation factor at room temperature. Only ML and aluminum phosphate bonded asbestos were evaluated after aging at 250 C. The small increase in dissipation factor for the ML insulation may indicate degradation but more likely is related to dielectric loss in the copper oxide which develops on the copper surface under the ML coating. The considerable decrease in tan δ with the asbestos insulated wire probably relates to a permanent loss of water in the aluminum phosphate bonding material.

The changes in dissipation at 23 C after aging at 120 C in air and vacuum are more interesting. In example, the dissipation factor of Formex increases after aging in air but shows no significant change after aging in vacuum. In contrast ML is slightly improved (lower dissipation factor) by aging in both air and vacuum at 120 C. The Phelps Dodge ML initially has a somewhat higher value of dissipation factor than the GE wire and is improved more by the thermal aging. Du Pont has reported that room temperature dissipation factor can be used to measure cure and on this basis the initial cure of the GE wire would be considered to be better.

The slight increase in tan δ for PVC after aging at 120 C may indicate degradation which is not yet measurable in the mechanical properties. The results after 120 days aging will be interesting in this respect. The small changes in the very low dissipation factor for Teflon after aging are not believed to be significant.

The comparison in tan δ at 23 C for the asbestos insulated wires before and after aging at 120 C is interesting. The values show no significant change for the ML coated asbestos without phosphate bond (the very small changes probably are due to differences in humidity equilibrium). In contrast, the dissipation factor of aluminum phosphate bonded asbestos is decreased markedly by thermal aging at 120 C due probably to the permanent loss of moisture from the aluminum phosphate. The somewhat greater decrease in the values after aging in vacuum as compared to air would seem to

confirm the belief that the loss of a volitile constituent like
moisture is involved.

The extremely low value of dissipation factor for the samples
measured in liquid helium at 4.2 K makes comparison useless. It
does not seem significant that one Formex and two of the Teflon
samples could be measured while all of the other values were below
the limits of sensitivity with an extremely sensitive bridge. From
the practical point of view the electrical loss at liquid helium
temperatures is so low that no practical problem should be encountered.

Changes in capacitance, however, can be used to study the
effect not only of thermal aging but also the effect of very low
temperatures. I should be noted in this respect also, that the
values measured include the effect of sample geometry and cannot
be translated into values of dielectric constant. The measured
values of capacitance are given in Table V and comparison in terms
of ratios is given in Table VI which will be used here because it
is easier to comprehend.

It should be recognized that moisture, polar characteristics
of the materials and density affect the value of capacitance (as
well as geometry). For example an increase in density will increase
capacitance which probably explains the small increase noted in
Teflon (a non-polar material) at liquid helium temperature. The
slight increase in capacitance for Teflon at 23 C after heat aging
may relate to small changes in geometry (thermal relaxation). In
contrast the more marked decrease in capacitance at 4.2 K for Formex
and particularly PVC probably relate to polar characteristics which
are "frozen out" at the low temperatures. Change in value for these
two materials at 23 C after thermal aging are probably also due to
changes in sample geometry resulting from slight thermoplastic flow.

The lack of significant change in the capacitance of ML insu-
lation is striking - even after aging at 250 C. It is known that
essentially no thermoplastic flow occurs with ML and the measure-
ments confirm it. Cure apparently does not change capacitance as it
does dissipation factor. The lack of change at cryogenic tempera-
tures is more surprizing and indicates little effect of molecular
polarization. The stability of capacitance with ML may be important
in some practical applications.

The changes in capacitance for the asbestos insulated wires
confirms the explanation for the changes noted earlier in dissi-
pation factor - a permanent loss of moisture after aging at 120 C
decreases the room temperature capacitance for aluminum-phosphate
bonded asbestos and the decrease is greater after aging in vacuum.
The large decrease in capacitance at 4.2 K for both asbestos insu-
lated samples indicates that at cryogenic temperatures the polar
effects of moisture in both aluminum phosphate and the asbestos are
"frozen out" as has been noted in earlier reports.

Table V
Effect of Thermal Aging on Capacitance (Values in pfd) – 1 Kc

Wire	at 23 C Before Aging	at 23 C After 60 da. 120 C in air	at 4.2 K After 60 da. 120 C in air	at 23 C After 60 da. 120 C in Vac.	at 4.2 K After 60 da. 120 C in Vac.	at 23 C After 60 da. 250 C in air	at 4.2 K After 60 da. 250 C in air
Teflon	13.49 13.95 12.71 11.87	13.94 14.49	14.88 17.21	12.56 12.82	13.48 13.62		
PVC	26.92 42.25 25.77 26.75		23.80 31 60	29.42 31.24	22.90 23.96		
Heavy Formex	71.82 67.64 51.20 53.31	79.13 70.08	52.83 60.52	53.40 59.94	47.68 53.39		
HML (GE)	55.25 52.58 50.36 63.48 53.57 59.17	55.59 53.98	55.07 51.62	49.50 57.52	50.23 55.71	57.20 59.90	50.27 56.76
HML (PD)	62.53 60.51 55.40 59.75	60.41 59.44	58.57 59.47	54.36 56.97	58.57 59.47		
Aluminum-Phosphate Felted Asbestos	103.4 4.4 ??.? 102.? 99.7 114.0	80.19 70.82	24.40 29.73	58.44 64.27	24.58 25.13	64.77 75.87	24.95 27.17
ML Coated Felted Asbestos	95.93 71.09 90.84 70.06	104.97 80.91	21.71 18.75	97.52 73.32	21.68 18.82		

Table VI

Effect of Thermal Aging on

1 Kc Capacitance (Avg. Ratio – Value at Condition Shown to Initial Unaged Value at 23 C)

Wire	at 4.2 K* Before Aging	at 23 C After 60 da. 120 C in air	at 4.2 K After 60 da. 120 C in air	at 23 C After 60 da. 120 C in Vac.	at 4.2 K After 60 da. 120 C in Vac.	at 23 C After 60 da. 250 C in air	at 4.2 K After 60 da. 250 C in air
Teflon	1.03	1.04	1.17	1.04	1.11		
PVC	0.72	----	0.885	1.16	0.89		
Heavy Formex	0.87	1.07	0.81	1.08	0.97		
HML (GE)	1.11	1.015	0.99	0.95	0.935	1.035	0.95
HML (PD)	----	0.98	0.96	0.97	1.025		
Aluminum Phosphate Felted Asbestos	0.175	0.81	0.29	0.61	0.24	0.66	0.25
ML Coated Felted Asbestos	----	1.115	0.25	1.06	0.25		

* Values from fourth quarterly report

Studies of Crushing

Failures have sometimes occurred in large magnet coils oper-
ating at cryogenic temperatures. The failures seem to have occurred
as the result of crushing in the insulation at cross-overs between
wires. In consequence attempts have been made to study this situ-
ation quantitatively. In this initial program, measurements have
been made at room temperature and in liquid nitrogen. The test
sample (wire) has been supported in a ½ round slotted anvil and
subjected to pressure from either a .010 in. or .025 dia. piano wire
rod held in a small fixture and supported in an Instron tensile
machine so that the rod is held at a right angle with the wire. The
load is applied from the Instron by a saddle arrangement through a
thin walled stainless steel tube to minimize heat losses from the
test assembly which for cold tests is held inside a conventional
Dewar flask and kept cold by immersion in liquid nitrogen. The
assembly in the Instron (without the flask) is shown in Photo 1.
The anvil, rod and a spherical contact member to be used in future
studies are shown in Photo 2.

It was hoped that discontinuities in the stress-strain chart
made as load was applied to the sample could be used to indicate
the point at which cracking or crushing occurred in the insulation
of the test sample. So far such stress-strain curves have not
been sensitive to cracking which occurs for example in Formex but
the curves do indicate the gross shattering which occurs with PVC
in liquid nitrogen.

To date, tests have been made with up to 70 pounds applied to
the .010 in. diameter rod and 500 pounds applied to HML insulated
wire using the .025 in. diameter rod. In liquid nitrogen PVC
insulated wire is so brittle that the weight of the saddle (4.7
pounds) on the rod will by itself produce cracking. Formex insu-
lated wire cracks and spalls in liquid nitrogen during the time
that 50 pounds is slowly applied to either size rod. The load at
which cracking actually occurred could not be determined from the
stress-strain chart and more tests will be needed to make a precise
determination. HML insulated wire in liquid nitrogen has not been
damaged by 70 pounds applied to the .010 in. rod or 500 pounds
applied to the .025 in. rod. PVC, Formex and HML are not damaged
by the loading tests when made at room temperature.

The rod loading tests deform the copper leaving a depression
to about half the diameter of the wire with the smaller rod and
substantially more with the large rod. It is amazing that ML
insulation is sufficiently ductile at liquid nitrogen temperature
to take such gross deformation without failure. Such gross deform-
ation is probably not representative of at least most practical
situations. Consequently, the development of shear as well as
straight compression load will be attempted. The next measurement
will be made with a loaded ball supported between two wires as
sketched below.

loaded sphere

wires supported in anvil
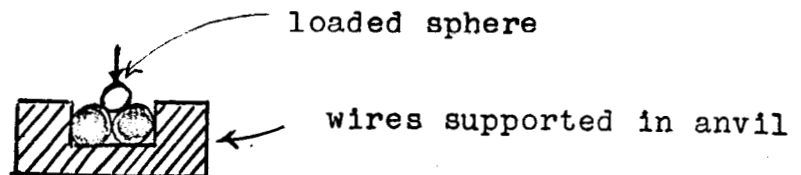
Flat Ribbon Cable

Mandrel flexibility tests for a polyester (Mylar) insulated ribbon cable have been described in the fifth quarterly report (pages 5 & 6). In these tests cracking was obtained on $\frac{1}{4}$" and $\frac{1}{2}$" mandrels but not on a 1" mandrel except where the sample was over-stressed at the point of attachment. Similar tests for three other ribbon cables are summarized in Table VII. Sample I made with H film (an aromatic polyimide material from Du Pont with chemical composition similar to ML enamel) exhibits superior performance. Sample II with an exactly similar geometry to that of Sample I but made with Mylar polyester film cracks on a larger mandrel. The much thicker Sample III cracks on a 1" mandrel despite construction with FEP Teflon. The relatively poor performance is assessed at least in part to the heavier construction.

Attempts are still being made to obtain H film insulated flat ribbon cable hot bonded thermoplastically with thin FEP Teflon film.

Measurements on flat, ribbon cable have been limited so far to mandrel flexibility which is believed to be the critical requirement for cryogenic applications. When an optimum construction is decided upon additional tests are merited.

Dielectric Properties of Cryogenic Liquids

Time has been unavailable during the quarter for breakdown measurements on cryogenic liquids using the new test assembly described in the fifth quarterly report. However, it now seems feasible to make useful capacitance and dissipation factor measurements. The new General Radio bridge greatly improves the precision possible for loss measurements. In addition, Mr. J. M. Atkins has made an ingenious suggestion to use a high voltage vacuum capacitor mounted in a glass envelope as an electrode system. A glass side arm will be fused into the glass envelope so that a vacuum may be drawn on the 1000 pfd. capacitor while immersed in a cryostat. Pure helium, nitrogen or hydrogen can then be admitted and allowed to condense around the electrodes, in this way accurate dielectric constant and dissipation factor measurements should be relatively easily made.

PROGRAM FOR JANUARY AND THE SEVENTH QUARTER

In January the voltage breakdown measurements of aged samples will be continued. Dielectric measurements on aged samples will be made in liquid nitrogen in the hope that the dissipation factor will be within the sensitivity range of bridge and will provide useful information on the aging process. Studies of cracking resistance will also be continued.

Samples aged in air and vacuum at 120 C will reach 120 days and be removed for test early in March. Many of the results of such aging should be available for the next quarterly report. In the next quarter also, studies of the dielectric properties of cryogenic liquids will be resumed.

Table VII

Repeated Mandrel Flexibility in Liquid Helium
on
Flat, Ribbon Cable

|	Cable	Mandrel Dia.-In.	Remarks
I	Polystrip (H-100-C-25) Resin Bonded H-Film Conductor .003" X .040" Spacing 0.100"	$\frac{1}{4}$	Broke only where over stressed close to mandrel attachment. No other damage.
		$\frac{1}{2}$	Cracked only where over stressed as above.
II	Polystrip (P-100-6-12) Resin Bonded Mylar Conductor .003" X .040" Spacing 0.100"	$\frac{1}{4}$	Complete Failure - Film delaminates loosens and pulls off.
		$\frac{1}{2}$	Cracks only where over stressed close to point of attachment to mandrel. No other damage
		1	Same as for $\frac{1}{2}$ inch mandrel
III	Polystrip (TX-156-6-20) .010 in FEP Teflon Conductor .010" X .078 Spacing 0.150	1	Film cracked across the strip at spacings $\frac{1}{2}$" to 1" apart.
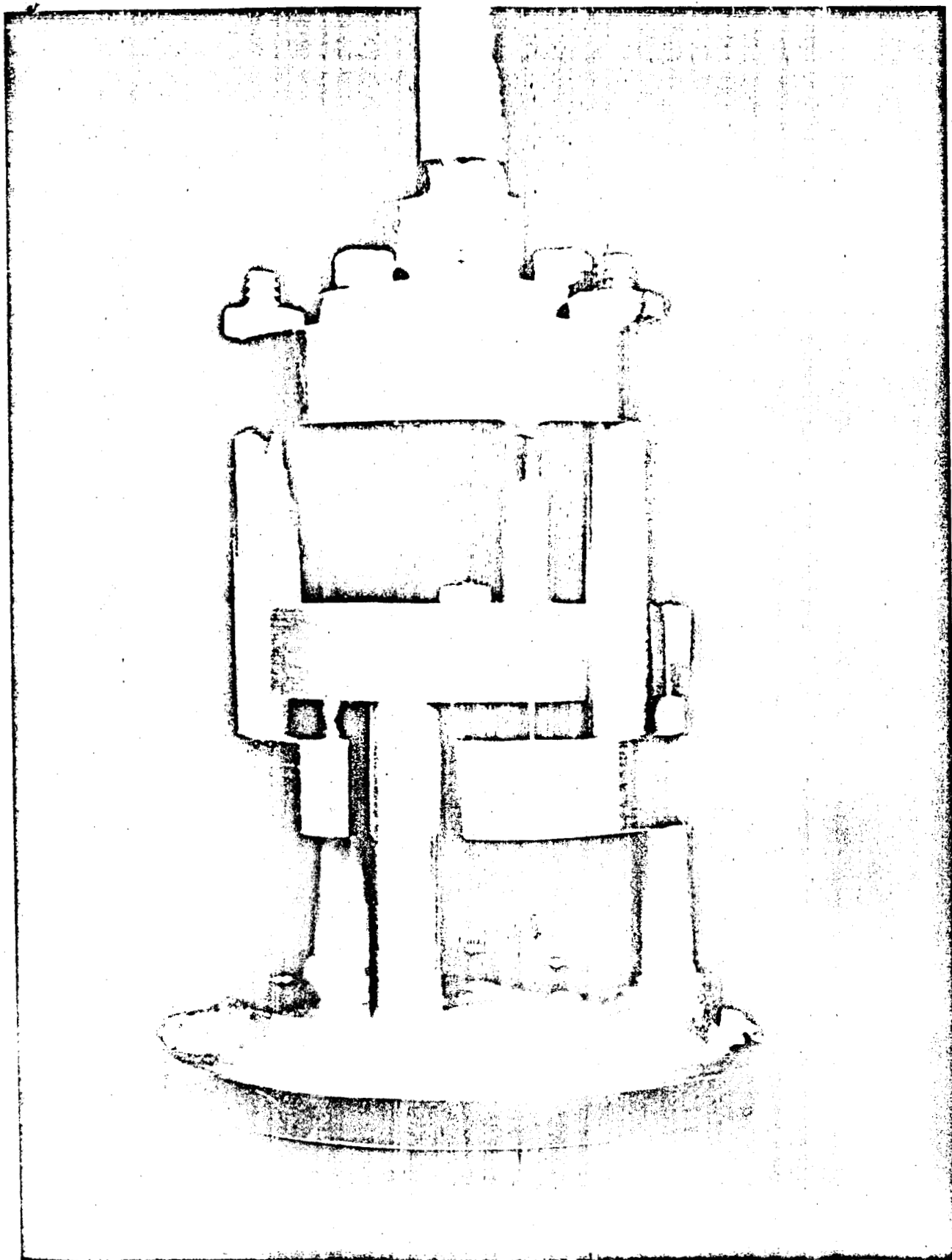
Photo 1: Crushing Fixture for INSTRON
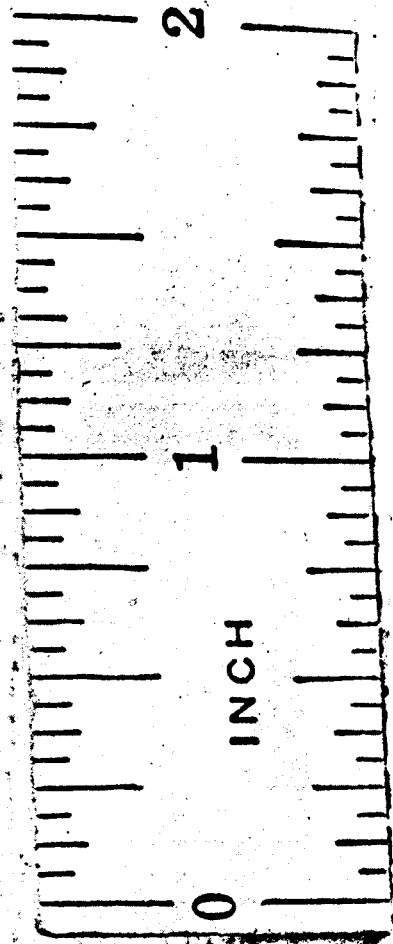
Photo 2: Anvil, Pressure Rod & Ball for Crushing Fixture